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CONF-840612--16

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AN INTEGRATED EMISSIONS MODEL SYSTEM FOR ANALYSIS OF ACID DEPOSITION CONTROL STRATEGIES

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For Presentation at the 77th Annual Meeting of the
Air Pollution Control Association
San Francisco, California June 24-29, 1984

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An Integrated Emissions Model System for Analysis of Acid Deposition Control Strategies
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Background

The Acid Precipitation Act of 1980, passed by Congress as Title VII of the Energy Security Act of 1980 (PL 96-294), established an Interagency Task Force on Acid Precipitation and called for a comprehensive ten-year research program to identify causes of acid precipitation, evaluate its effects, and identify potential mitigation measures.

The Interagency Task Force formulated a research effort, the National Acid Precipitation Assessment Program (NAPAP) which operates through a set of ten Task Groups, each with specific research responsibilities and members from a number of federal agencies. Task Groups A through H are responsible for improving scientific understanding and for the development of technical models and data bases in their specific areas of responsibility. The responsibility for integrating the results from these activities is assigned to Task Group I (Assessments and Policy Analysis). ADAS, an interagency staff housed at the U.S. Environmental Protection Agency, is the operational arm of Task Group I with responsibility for implementing the integrated assessment program. The goals, approaches, and recent progress of NAPAP is summarized in its annual report.[1]

The ultimate objective of NAPAP is to provide a scientifically based framework for policy analysis. This framework will include a comprehensive cost-benefit analysis of alternative combinations of emission control and direct mitigation measures to lessen the adverse effects of acid deposition. This objective is to be accomplished through the development and application of an advanced integrated assessment methodology. The methodology will be built around a system of linked models and data bases which can be used to simulate major components of the acid deposition phenomenon; these components include emissions, effects, atmospheric/deposition processes, and monetary valuation of effects.

The major outputs from the NAPAP research program will be a series of assessment documents to be produced in 1985, 1987, and 1989. The 1985 assessment will focus on damages due to acid deposition and uncertainties in the relationship between emissions of acid deposition precursor pollutants and actual deposition. It may also include some discussions of the implications of scientific uncertainty on policy decisions. The report will provide an update of the state of scientific knowledge in all areas relevant to acid deposition and the information regarding uncertainty will provide information to assist in directing future research efforts. It will not, however, present fully integrated analysis results. Critical components of the methodology described above for integrated assessment will not be available in time to support the 1985 assessment.

This paper discusses some of the key model components which will contribute to this series of assessments. It focuses on the capabilities being developed for estimating future man-made emissions of pollutants relevant to acid deposition, and the costs and changes in emission patterns expected from alternative emission reduction policies. These capabilities are being developed principally by Task Group B (Man-Made Sources) which is also playing a major role in assisting the Acid Deposition Assessment Staff (ADAS) in the development of integrated systems and their application to produce the required assessments. The paper describes the system of models being

developed for these purposes and some of the proposed linkages of these emission analysis tools with models of the relevant atmospheric and deposition processes. The paper focuses on the initial model system, which will be integrated and tested over the next year, but does suggest some enhancements which will be available in later years. Finally, the paper provides some illustrative results from early testing of some of the prototypes of models to be used in the assessments. Many of the details of the modeling components and proposed analyses described in this paper are currently under review by the appropriate Task Groups. These details may be revised somewhat in the next few months as a result of these reviews.

Overview of the Emissions Modeling System

The integrated assessment framework being developed by NAPAP is designed to allow for comprehensive analysis of alternative emission control and mitigation policy options. Given a set of baseline energy and economic projections, this design will support comprehensive comparison of the total costs and benefits of alternate policy scenarios.

Figure 1 provides a graphic representation of the emission strategy analysis components of this framework and their relationship to atmospheric and policy evaluation components. Baseline scenarios which reflect alternative assumptions about future economic growth and energy availability drive detailed sectoral emission models and a less detailed long-term model extension. These models project future emission patterns which drive an atmospheric assessment model or models to produce baseline deposition patterns. The sectoral models also generate control cost estimates and modified emission patterns for emission control policy scenarios. These are used in the policy evaluation process to analyze and compare the emission policy options.

The core system of models and data bases will be designed for a level of resolution which is consistent with obtainable data and state-of-the-art modeling. The system will address the time period from 1980 to 2030. More detailed analysis will be provided for the time period between 1980 and 2000. Emission projections will be at the state level with the exception of utilities which might be provided at the plant level. Annual total emission projections will be provided with seasonal variation for each year during the period. A less detailed level of analysis will be provided by the Emissions Strategy Integration Model (ESIM).[2] This model combines summary outputs of the detailed sectoral models with simplified atmospheric relationships. This will allow for analysis of cost-effectiveness of alternative emission strategies relative to deposition objectives.

The time period 2000 to 2030 will be projected at a more aggregate level. Long-term trends in emissions for the source/sectoral/ pollutant combinations will be estimated, including the emissions projected from source control scenarios. Emission estimates for this period will be provided at the regional level and possibly the state level in ten-year increments.

The emissions analysis capability is being designed as a modular, staged system to ensure the flexibility needed to respond to evolving assessment needs and inputs.[3] The modular structure allows for replacement of simple capabilities with successively more sophisticated

components as needed for analysis and as available from model development projects. The basic emissions model system shown in Figure 1 will be assembled and tested during the next year. In future years, more sophisticated components and other refinements to the system will be incorporated.

A more detailed description of the emission model system is provided in the "General Specifications" document produced by the Man-Made Sources research task group.[4] These specifications guide the emissions model development projects and provide specific information regarding attributes which the models and their documentation should contain. The result of this process is a consistent set of models and documentation to be utilized within the modeling, integration, and assessment program.

Key Components

As illustrated in Figure 1 and discussed in the previous section of this paper, there are many components to this analysis. Several key components of the initial model system are briefly described below. These are the energy and economic inputs which drive the sectoral emission models; the emission models for the utility, industrial, and transportation sectors; less-detailed models for emissions from industrial processes; a residential and commercial sector model; and the long-term model extension capabilities to the year 2030.

A set of baseline energy and macroeconomic forecasts is needed to drive the sectoral models and to produce consistent estimates of future emission levels and costs by pollutant and by sector. This is clearly a very crucial component of the integrated model system and one which is likely to be subject to close scrutiny. Difficulties arise from several sources: 1) the need to develop projections out to the year 2030 (generally, current models have a shorter time horizon, for example 2010 or 1990); 2) the need to disaggregate national projections to the regional or state level; and 3) the possibility that a control scenario could cause significant feedback to the energy/economic assumptions which must be accounted for. For the initial testing, projections to 2030 are being developed as simple extrapolations of available data to 2010. A set of baseline energy and economic scenarios will be developed from existing sources. These will include some scenarios that are more optimistic (e.g., high economic growth and low interest rates) and some that are more pessimistic (e.g., low growth and high interest rates). It is anticipated that a suitable set of baseline scenarios can be assembled from existing projections from energy sector and macroeconomic forecasting models and the judgment of experts in government and industry.

For the 1987 (and later) assessments, attention will be paid to obtaining more detailed energy and economic driving inputs. A review has already begun of options that might be available and desirable for the 1987 and subsequent assessments.

The utility sector is being modeled by the Advanced Utility Simulation Model (AUSM) which is being developed under the support of Task Group B by a consortium of three universities led by the University of Illinois. AUSM consists of a set of modular components, some of which will require inputs from the energy and economic driving model. Required inputs include

state-level forecasts of fuel prices, population, and economic activity indicators (i.e., personal income, earnings, and employment). It should be noted that default values for all of these are contained within AUSM.

A single state version of AUSM was made available for testing in early 1984. It is capable of projecting emissions of SO_2 and NO_x to the year 2000. The single state model can be easily run for multiple states in succession to evaluate regional and national policies. A more sophisticated national level AUSM is under development but will probably not be available in time to use in the 1985 assessment. The national AUSM will have improved capabilities for addressing the costs and benefits of regional emission control strategies and will be included in future analyses.[5,6,7] In addition, an ability to model SO_4 emissions will be available.

For the industrial sector, the Industrial Combustion Emissions (ICE) model is being developed under Task Group B sponsorship. The ICE model requires input information regarding energy demand, industrial growth rates, and costs of operation. Delivery of a prototype ICE model for projecting industrial boiler emissions is scheduled for mid to late-1984. This version will include the capability to estimate emissions of SO_2, SO_4, and NO_x to the year 2000 and will be incorporated into the initial model system. An improved version, expected to be available in 1985 or beyond, will also be capable of examining the non-boiler industrial emissions of SO_2 and NO_x.

A detailed model for evaluating stationary source emissions of volatile organic compounds (VOC) is also under development but is not expected to be available in the initial system. It is expected that the Man-Made Sources Task Group will provide simplified projections of future non-boiler industrial emissions of SO_2 and NO_x and stationary source emissions of VOC. Cost and performance estimates for a few selected control options will also be provided.

For the initial system, transportation emissions of SO_2, NO_x, and VOC will be generated based on nationwide estimates of vehicle miles traveled for long-distance and local passenger and goods movements. Emission factors will be produced from the MOBILE2.5 or MOBILE3 models.[8] An existing approach, such as the Argonne transportation model[9] or the Department of Energy Highway Fuel Consumption Model, will be adopted to provide projections of Vehicle Miles Travelled consistent with overall energy/economic forecasts.

The approach for modeling residential and commercial emissions for SO_2 and NO_x will be based on fuel use projections and emission factors for fuel combustion. Fuel use for the residential and commercial sectors will be provided at the national level by the energy driver model. Disaggregation to the state level will be achieved using population growth for the residential sector and employment growth for the commercial sector. The methodology used for projections in the driver models will be carefully reviewed but independent models of fuel use, population, or employment growth for the residential and commercial sectors will not be developed. Emission projections for SO_2 and NO_x will be calculated at the state level based on the state fossil fuel use projections by type (residual oil, distillate oil, or gas) using appropriate emission factors and assumptions. Methods of determining state level VOC emissions for the residential and

commercial sectors are being studied.

The need to develop emission and deposition projections over a 50-year time horizon to 2030 is driven by two considerations. First, the time scale for acid deposition effects to certain receptor systems, for example, forests and soils, may be long, especially if accumulation is a significant mechanism of damage. Hence, long term emission and deposition estimates may be needed to evaluate changes in effects. Second, emissions of major precursors are expected to decline significantly as older plants with high emission rates are replaced by new plants controlled to stringent emission levels by New Source Performance Standards and as new control technologies are introduced and installed in response to revised environmental standards. The long-term effectiveness of alternative control strategies is also very dependent on utilities' unit retirement policies.

Two guiding principles will be followed in developing a long-term emissions model extension: transparency and continuity. The modeling system will not attempt to make detailed forecasts of the state of the world fifty years from now. Rather, the system will provide detail sufficient to evaluate broad trends in emissions that might be expected as a result of major changes in the stock of emitting facilities. Such changes might be deployment of electric vehicles, accelerated or delayed retirement of coal-fired power plants, and penetration of new energy or control technologies. The methodologies will be simple and transparent such that the analyst can easily ascertain the underlying reasons for the trends and make general conclusions while acknowledging the considerable uncertainty involved in projecting this far into the future.

It is also important that continuity be maintained between the detailed forecasts provided by the sectoral models (to the year 2000) and the long-term extension model (beyond the year 2000). In other words, a "seamless" interface is desirable. This will be accomplished by extending assumptions in the sectoral models as smooth trends, and using the year 2000 runs from the sector models as initial inventories of sources for the extension model.

ESIM is a computerized system designed to permit analysis of various combinations of pollutant species, emission sectors, geographic regions, control scenarios, and control costs. Inputs to the model will be cost and performance information for control strategies selected from the sector models described above. In addition, source-receptor relationships and uncertainty ranges will be provided by the atmospheric science portions of NAPAP. ESIM will be capable of generating a cost-effectiveness estimate for any specified combination of controls, emissions, and source-receptor inputs. Cost-effectiveness will be defined as the total cost of a strategy divided by the predicted reductions in deposition in specified regions. In addition, given a specified target region, or set of regions, and a set of estimated baseline emissions and control costs, the model will approximate the most cost-effective strategies. This can be done in two ways. A deposition target(s) or deposition function(s) can be specified and the model used to approximate the least cost pattern of control actions. Deposition functions are not currently available but could ultimately be quantitative relationships between changes in deposition and expected damage in a receptor region. Also, a level of control (either in tons of reduction or dollar cost) can be

specified. In this case, the model will indicate how this reduction should be allocated by source region, pollutant, and sector to achieve maximum reduction in deposition in targeted regions.

Plan for Early System Testing

The initial emission modeling system will be assembled and tested over the next year. Baseline emission projections will be produced based on readily available alternative forecasts of economic activity and associated energy supply and demand patterns. The emission model system will be applied in order to project emissions of sulfur and nitrogen oxides and VOC based upon alternative input assumptions. Results will be presented for the period 1980 to 2030. The model system will also be applied to provide cost and performance information for a range of emission control options covering all major source sectors of SO_x and NO_x. Some VOC reduction strategies may also be included. In general, analysis will be at the state level for 48 states. Some strategies will also be evaluated for a smaller number of states.

Working with an oversight committee of researchers and policy analysts, ADAS will propose a representative range of policies and combinations of policies by mid-1984. Selected policies could include tax and financial incentives, conservation measures, and other policies which indirectly effect emissions, as well as direct emission control regulations. Policies will be evaluated using available modeling capabilities.

These models will be operated for the selected range of SO_x and NO_x control strategies. Outputs will be presented as state-level costs and emission changes for selected strategies and combinations. Secondary impacts such as employment shifts and coal movements will be provided where available. If sophisticated models are not available, simpler models will be used to provide estimates of cost and emission reductions for a limited number of control options.

Uncertainty ranges for modeled outputs will be estimated by sensitivity runs of the models. Estimates of uncertainty will be calculated for key input data such as emission factors, coal sulfur content, control costs, etc., based initially on the uncertainty in the 1980 emissions data base. In addition, alternative baseline emission scenarios derived fron energy and economic growth assumption models will be operated with inputs varing across these ranges of uncertainty to produce ranges around output estimates. Also, emission and cost estimates will be compared with other estimates available in the literature and major inconsistencies will be explained if possible.

For all sectors, qualitative estimates of uncertainty will be provided by the researchers producing the emission and cost estimates and extensively reviewed by outside experts.

Sensitivity analysis of selected emissions policies will be conducted with emissions strategies for the continental United States and selected subsets representing (i.e., 31 states, 21 states, etc.). The initial focus will be on SO_x although NO_x control will be included when atmospheric source-receptor information is available. Resolution for controls will be state level or finer. Sensitive areas will be as defined in the U.S.-Canada

Work Group II report for illustrative analyses.[10] Othe· regions will be designated for future analyses.

The organizing analysis tool for this effort will be the ESIM described above. Control cost and performance inputs will be selected from the available results of the emissions sector models. A specific analysis effort is currently underway to develop source-receptor relationships and uncertainties for the testing analysis.

The model will be exercised for a range of scenarios and across uncertainty ranges. Results will indicate how the cost-effectiveness of each strategy analyzed changes due to changes in input corresponding to current uncertainty. They will also show what the most cost-effective options would be under each set of assumptions. Analysis of this type eventually will allow conclusions to be drawn concerning which policies are relatively cost-effective across a range of uncertainties. In the early testing, it should be apparent if particular components of the existing uncertainty have particularly large effects on cost-effectiveness of policy options. This should help to establish priorities for additional research.

It is expected that the result of the above described analyses will provide a useful compilation of information relevant to policy decisions. It is expected that this will represent, in many ways, a substantial improvement over previous acid deposition policy analyses. However, it is extremely important to emphasize the limitaitons of the analysis that will be possible in the early testing period. Many of the component models and data sets used in the analyses will be preliminary or prototype versions as opposed to the fully developed and peer reviewed capabilities envisioned later. This obviously implies larger ranges of uncertainty around the estimates of emissions and control costs. In addition, scientific uncertainties in the atmospheric source-receptor relationships are still expected to be significant. As a result, the combined uncertainties in the policy sensitivity analyses may be so large that is not possible to clearly distinguish between alternative policies on the basis of cost-effectiveness.

In addition, the analysis will not include quantitative relationships between changes in deposition and changes in effects on industrial and aquatic ecosystems and on man-made materials. Thus it will not be possible to include estimates of the value, in economic or other terms, of changes in deposition related to any given emission control policy. The analysis will only provide a portion of the comprehensive cost/benefit analyses or utility analysis which is the ultimate objective of NAPAP. In the presentation of the results of these partial analyses, every effort will be made to identify those elements of the decision analysis problem which will not be provided and, therefore, must be evaluated judgmentally if decisions are to be made in the near term.

Illustrative Results

To test the capabilities of the preliminary version of ESIM, a series of illustrative analyses using currently available data was conducted. These analyses estimated the cost and emission implications across a selected series of emitting sectors of (1) meeting absolute emission reduction targets and (2) meeting deposition reduction targets in one or more selected target sensitive receptor areas. The results should be considered to be illustrative as much

of the input data is preliminary and of uncertain quality.

The sources of each of the major sets of data are discussed and illustrations of data actually used in the analysis are presented below. Data on emissions and cost were available for electric utilities, industrial boilers (coal and oil-fired), smelters, cement plants, and petroleum refineries. Utility data were obtained from E.H. Pechan & Associates' AIRCOST model[11] and data for the remaining source sectors were provided by Argonne National Laboratory.

Examples of utility emissions/cost data are provided in Figure 2. Figure 2 (top) illustrates utility control costs for two states of interest, New York and Ohio. Similar data are provided in the model for other states. Figure 2 (bottom) provides an illustration of utility and nonutility control costs for New York (UT is utility, IB industrial boiler, SM smelter, CM cement plants, and PR petroleum refineries). For some other states, the relative picture might be considerably different although absolute emission reductions achievable from nonutility sources would still be limited.

Data relating source emissions to deposition in the Adirondacks and other receptor regions was obtained from one of the U.S.-Canada Memorandum of Intent (MOI) studies. The results presented here should also be considered to be illustrative as there are major scientific uncertainties about these source-receptor relationships which have not been resolved in any existing models. The MOI data were used because they represent an extensive data set currently publicly available and consider a variety of models representing different methodologies. Of the seven models in the MOI study, three were selected for inclusion in the present study along with a "pseudo model" which represented the average of the coefficients from all seven of the models. It should be noted that several of these models have been modified extensively since being used as inputs to the MOI report. Figure 3 illustrates some of the data available from these models. Selected data elements from these models are shown in Figure 3 (top); these data relate deposition in the Adirondacks to emissions in New York and Ohio. The Adirondacks region is one of nine receptor regions for which data were available from each of the MOI models. Figure 3 (bottom) converts these matrix elements to relative deposition ratios for the two source regions. It is these ratios that can be traded off against the relative cost differential information presented in Figure 2. The relative ratios differ by as much as a factor of two indicating considerable uncertainty in the source-receptor relationship information.

To illustrate the tradeoffs between emissions, control costs, and source-receptor relationships, a series of analyses was conducted using the ESIM system along with the data discussed above for all 48 states. Three cases were considered, the first concerned with achieving only a specified level of emission reductions, the second concerned with achieving a specified reduction in sulfur (both wet and dry) deposited in the Adirondack region, and the third concerned with achieving some level of deposition reduction in each of the nine regions considered in the MOI study. For the second and third cases, source-receptor information from the selected set of the available atmospheric models was utilized.

Figure 4 (top) illustrates control costs (all in 1982 dollars) for various levels of overall cost-effective emissions reduction for the nation, along with the effects on deposition, in the Adirondack region. The upper

cost curve represents a case in which only utility sources were controlled and the lower curve includes both utility and non-utility sources. For reductions of between zero and four million tons, only utility sources are controlled; above eight million tons, the difference in costs between the two cases becomes more significant indicating relatively greater quantities of cost-effective reductions from non-utility sources. Also illustrated in this figure is the resulting deposition reduction which would be achieved in the Adirondacks based on the mean of the seven MOI models. Note that these figures include the emission reduction effects but not the costs of compliance with current State Implementation Plan (SIP) provisions -- an overall reduction of approximately 1.3 million tons per year.

Figure 4 (bottom) illustrates results from the case which attempted to identify cost-effective control policies to achieve a 25 percent reduction in Adirondack sulfur deposition. The coefficients of the *MEAN*1 and *MEAN*2 pseudo models are the averages of all seven models but the *MEAN*2 case allows controls only on electric utility sources. The cost of achieving a 25 percent deposition reduction in the Adirondacks ranges from 0.6 to 1.0 billion 1982 dollars per year. The result from the *MEAN*1 case can be compared with a cost of over three billion dollars per year from Figure 4 (top). This indicates that, assuming the transport models are correct, control costs can be reduced substantially if only limited areas require deposition reductions.

Figure 5 illustrates cost and emission reductions needed to achieve a 25 percent deposition reduction in all nine of the MOI regions. The 25 percent figure is arbitrary and was selected only to illustrate the analytic capabilities of the modeling system. In fact, it is unlikely that each of the nine regions would require the same level of deposition reduction. The cost and emission reductions in Figure 5 are substantially greater than those of Figure 4 (bottom). One interesting observation based on these preliminary data is that the cost of control programs designed to achieve specified deposition reductions over the set of fairly widely spaced receptor areas used in the MOI study is not substantially higher than the cost of programs designed to achieve a similar level of cost-effective emission reductions without regard to deposition constraints. On the other hand, the fact that at least one of the models required a level of emission reductions (and consequent cost) substantially higher than the remaining models indicates that a fairly wide range of uncertainty exists regarding the costs of achieving the specified deposition reductions simulated for the present study.

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Figure 1

Components of NAPAP Emissions Cost Modeling System

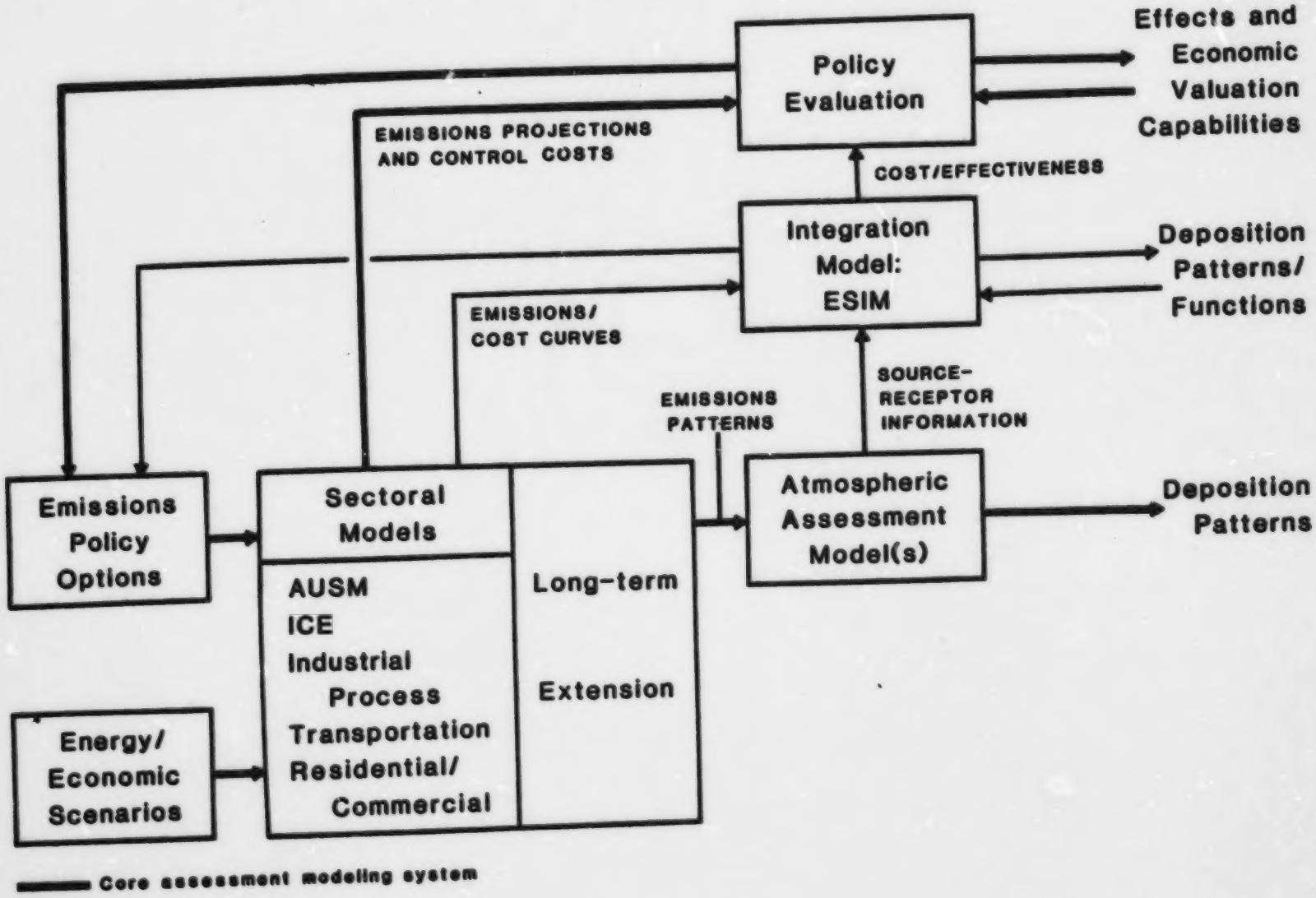
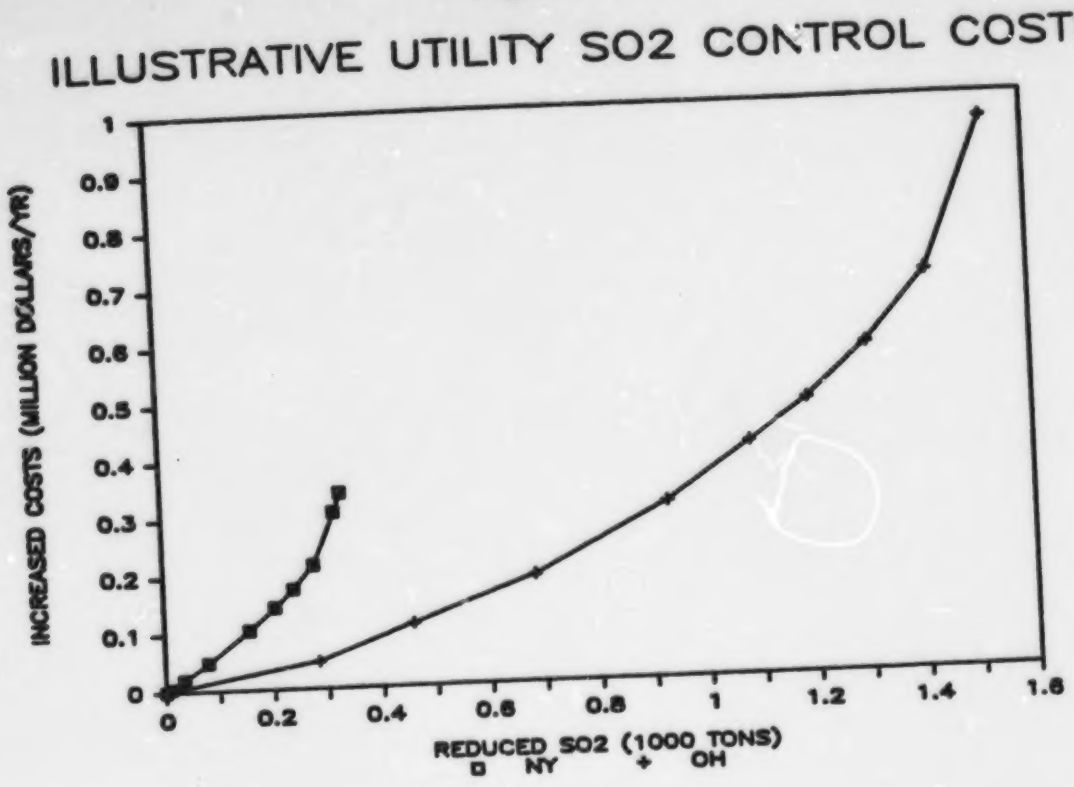


Figure 2


ILLUSTRATIVE UTILITY SO2 CONTROL COSTS
INCREASED COSTS (MILLION DOLLARS/YR)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
REDUCED SO2 (1000 TONS)
NY
OH

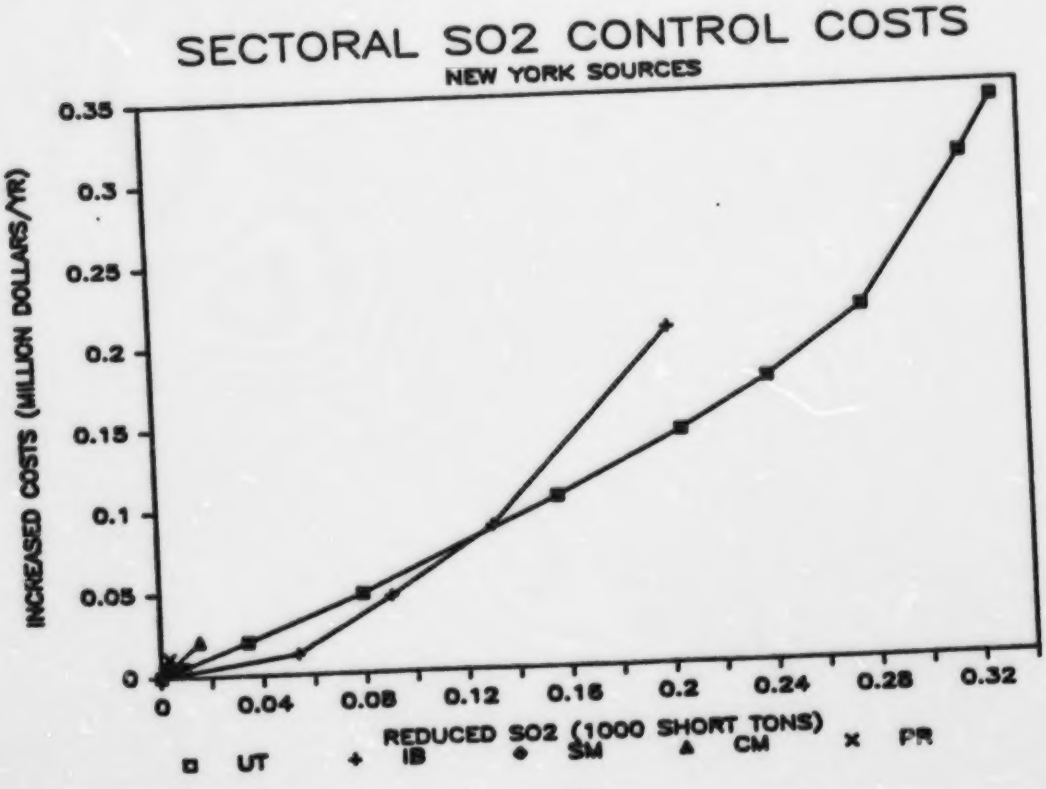
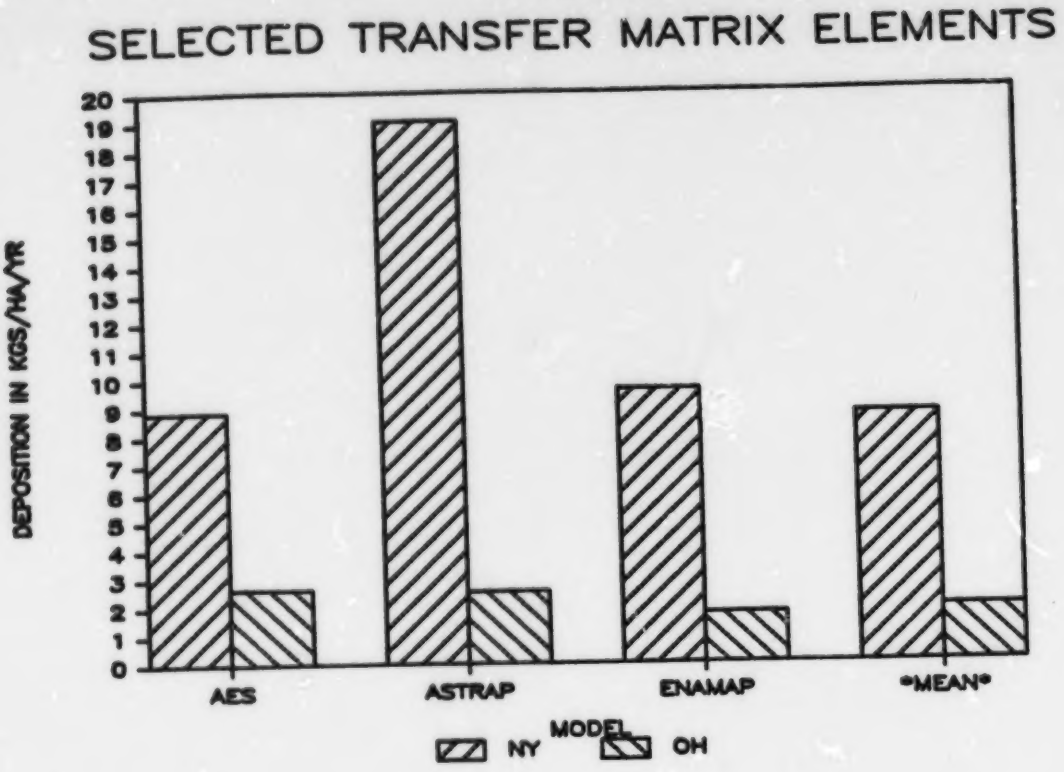

SECTORAL SO2 CONTROL COSTS
NEW YORK SOURCES
INCREASED COSTS (MILLION DOLLARS/YR)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
REDUCED SO2 (1000 SHORT TONS)
UT
IB
SM
CM
PR

Figure 3


SELECTED TRANSFER MATRIX ELEMENTS
DEPOSITION IN KGS/HA/YR
0
1
2
3
4
5
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AES
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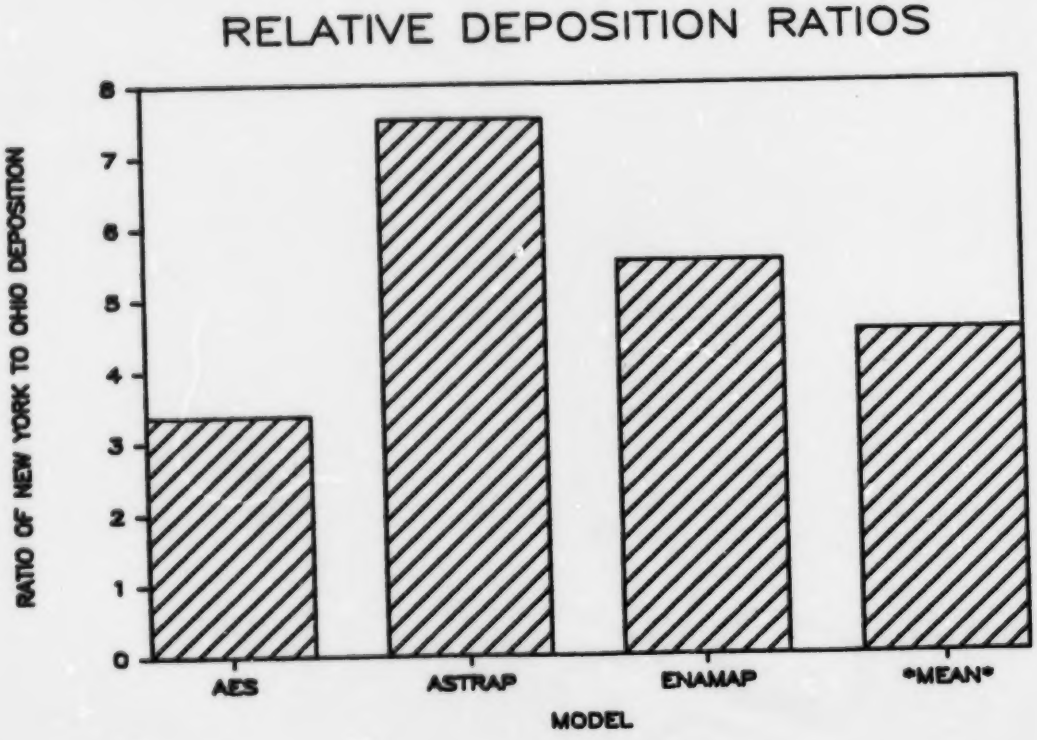
ENAMAP
MEAN
MODEL
NY
OH


RELATIVE DEPOSITION RATIOS
RATIO OF NEW YORK TO OHIO DEPOSITION
0
1
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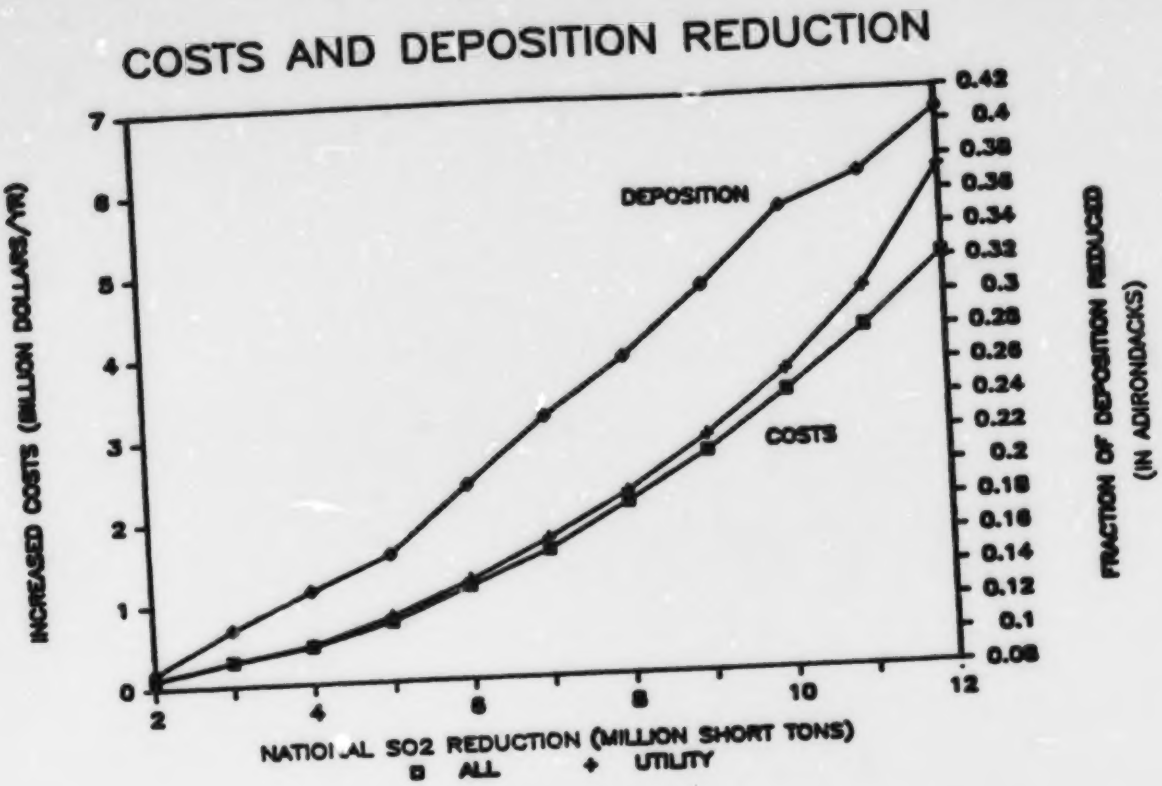
8
AES
ASTRAP
ENAMAP
MEAN
MODEL

Figure 4


COSTS AND DEPOSITION REDUCTION
INCREASED COSTS (BILLION DOLLARS/YR)
FRACTION OF DEPOSITION REDUCED (IN ADIRONDACKS)
DEPOSITION
COSTS
NATIONAL SO2 REDUCTION (MILLION SHORT TONS)
ALL
UTILITY

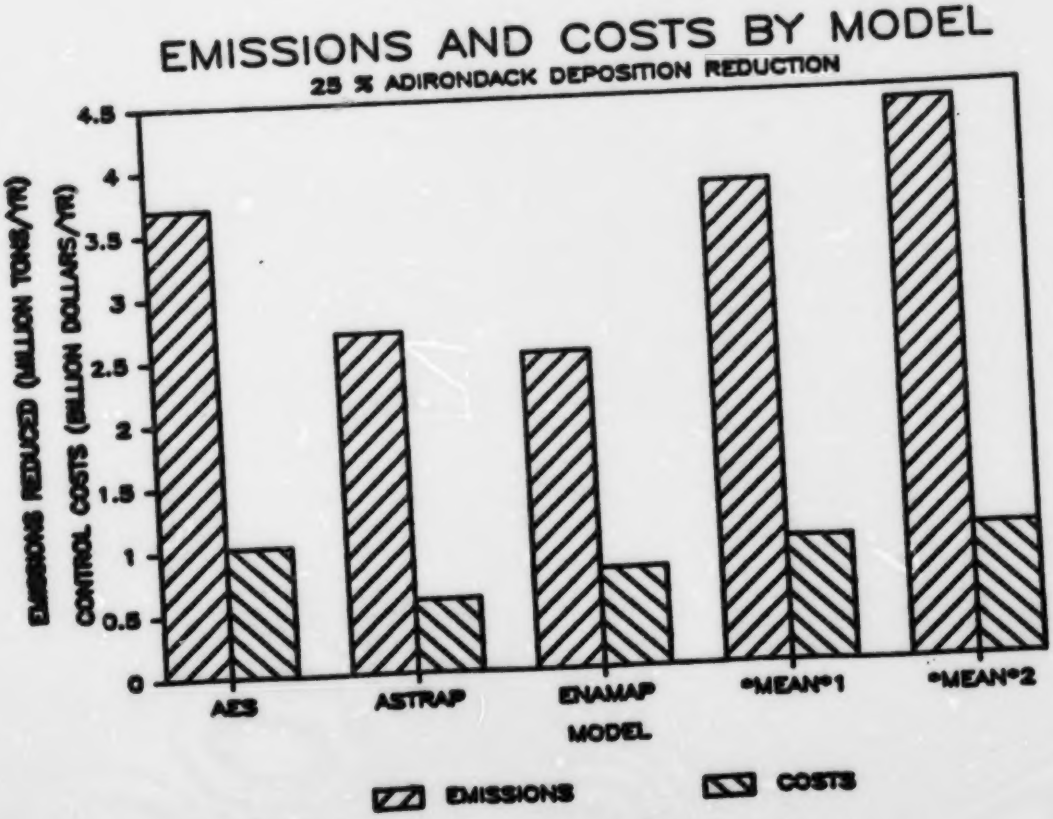
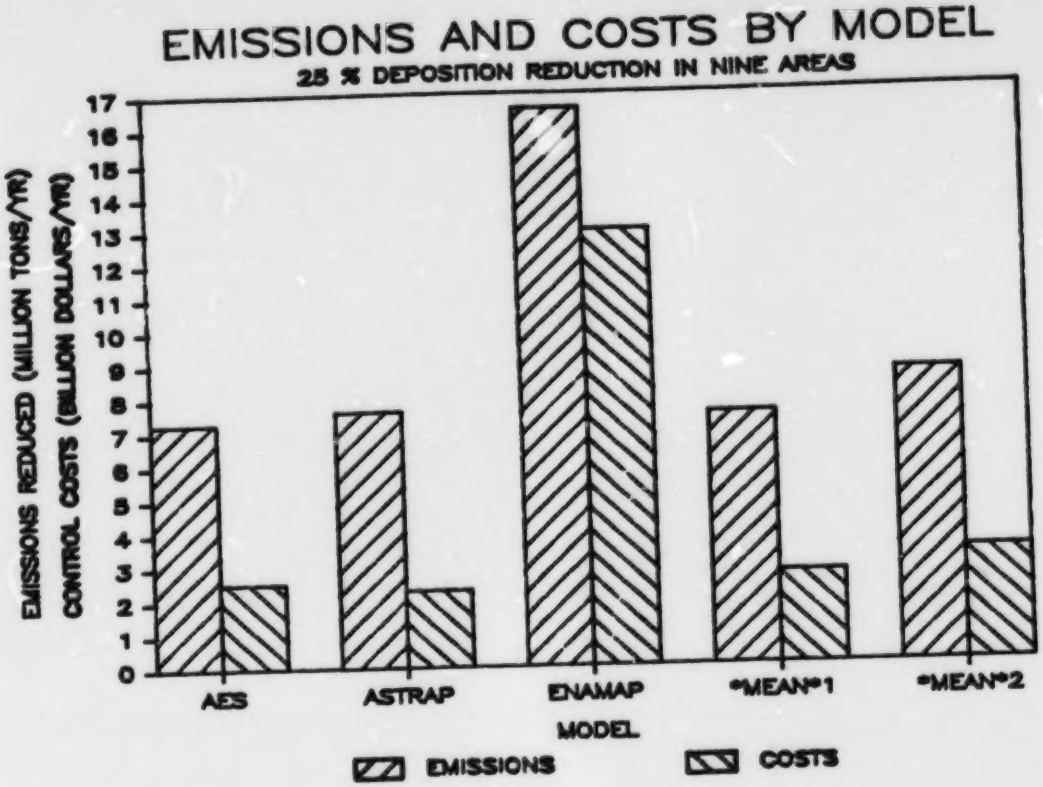

EMISSIONS AND COSTS BY MODEL
25 % ADIRONDACK DEPOSITION REDUCTION
EMISSIONS REDUCED (MILLION TONS/YR)
CONTROL COSTS (BILLION DOLLARS/YR)
AES
ASTRAP
ENAMAP
*MEAN*1
*MEAN*2
MODEL
EMISSIONS
COSTS

Figure 5


EMISSIONS AND COSTS BY MODEL
25 % DEPOSITION REDUCTION IN NINE AREAS
EMISSIONS REDUCED (MILLION TONS/YR)
CONTROL COSTS (BILLION DOLLARS/YR)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
AES
ASTRAP
ENAMAP
*MEAN*1
*MEAN*2
MODEL
EMISSIONS
COSTS